A pQCD-based Approach to Parton Production and Equilibration in High-Energy Nuclear Collisions *

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In this report, I presented a perturbative QCD (pQCD)-based picture of ultrarelativistic heavy-ion collisions. In this framework, a nucleus in the infinite momentum frame consists of many partons (quarks and gluons). The interactions among these partons can be divided into perturbative, which can be described by pQCD calculations, and nonperturbative, which can only be modeled phenomenologically. I demonstrate that pQCD processes dominate the underlying dynamics of heavy-ion collisions at extremely high energies. It is then reasonable to assume that the evolution of the initially produced partons can be described by pQCD processes. Using the initial conditions estimated by the HIJING Monte Carlo model, the following picture emerges:

(1) During the early stages of ultrarelativistic heavy-ion collisions, hard or semihard parton scatterings, which happen in a time scale of about 0.2 fm/c, produce a hot and undersaturated parton gas. This parton gas is dominated by gluons and is far from chemical equilibrium. Multiple hard scatterings suffered by a single parton during this short period of time when the beam partons pass through each other are suppressed due to the interference embedded in the Glauber formula for multiple scatterings. Interference and parton fusion also lead to the depletion of small x partons in the effective parton distributions inside a nucleus. This nuclear shadowing of parton distributions reduces the initial parton production.

(2) After the two beams of partons pass through each other, the produced parton gas in the central rapidity region starts its evolution toward (kinetic) thermalization and (chemical) equilibration through elastic scatterings and induced radiations. Further evolution of the parton gas toward a fully equilibrated parton plasma is dictated by the parton proliferation through induced radiation and gluon fusion. Though the gluon equilibration rate is reduced by the inclusion of the Landau-Pomeranchuk-Migdal effect, the gluon fugacity still increases rapidly toward its equilibrium value. Due to the consumption of energy by the additional parton production, the effective temperature of the parton plasma cools down considerably faster than the ideal Bjorken scaling solution. Therefore, the life time of the plasma is reduced to 4 - 6 fm/c before the temperature drops below the QCD phase transition temperature.

(3) The evolution of the quark distribution always lags behind that of gluons due to a smaller equilibration rate and the initial density. For heavy quarks, the equilibration rate is even smaller. Take charm quarks for example. The thermal production during the equilibration period is much smaller than the initial direct production, due to the small initial gluon fugacity and the short lifetime during which the temperature remains high enough to produce charm quarks. For the same reason, dilepton and photon production during the evolution of the parton plasma is also small because of small quark number density. Therefore, observation of large charm and dilepton enhancement would imply high initial gluon and quark density and thus a longer life time of the parton plasma.

(4) Even though the initial parton system is not in full equilibrium, a study of color screening shows that the system is already in a deconfined state with large average momentum (or effective temperature). Such a deconfined parton system, though not in equilibrium, will dissociate hadronic states such as the J/ψ. It was shown that the J/ψ can be substantially suppressed during the evolution of the parton plasma toward equilibrium. The measurements of this suppression can reveal the initial conditions and the evolution history of the parton plasma in high-energy heavy-ion collisions.

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